The Mission Accessibility of Near-Earth Asteroids

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Defining NEO Accessibility Factors

- **Astrodynamical**
  - Earth departure dates; **mission** Δv; **mission duration**; stay time; etc
- Physical
  - NEO size(?); rotation rate; dust/satellites environment; chemistry; etc
- Architectural
  - Launch vehicle(s); crew vehicle(s); habitat module(s); budget; etc
- Operational
  - Operations experience; abort options/profiles; etc

Astrodynamical Accessibility is the starting point for understanding the options and opportunities available to us.

Here we shall focus on Astrodynamical Accessibility.

Astrodynamical Accessibility (NHATS)

- Earth departure date between 2015-01-01 and 2040-12-31
- Earth departure $C_3 \leq 60$ km^2/s^2
- Total mission $\Delta v \leq 12$ km/s
  - The total Δv includes (1) the Earth departure maneuver from a 400 km altitude circular parking orbit, (2) the maneuver to match the NEA's velocity at arrival, (3) the maneuver to depart the NEA and, (4) if necessary, a maneuver to control the atmospheric re-entry speed during Earth return.
- Total round trip mission duration ≤ 450 days
- Stay time at the NEA ≥ 8 days
- Earth atmospheric entry speed ≤ 12 km/s at an altitude of 125 km

A near-Earth asteroid (NEA) that offers at least one trajectory solution meeting those criteria is classified as NHATS-compliant.

http://neo.jpl.nasa.gov/nhats/

Putting Accessibility Into Context

- What does "accessible NEO" mean? "Accessible" compared to what?
- Other solar system destinations:

Destination	**Total Δv (km/s)**	**Round-Trip Mission Duration (days)**
Lunar orbit	$\sim$5	$\sim$One to several weeks
Lunar surface	$\sim$9	$\sim$One to several weeks
Mars Surface	12.53	923 *(500 day stay)*
Elliptical Mars Orbit	6.29	923 *(500 day stay)*
Elliptical Mars Orbit	12.14	422 *(7 day stay)*
Elliptical Mars Orbit (w/ Venus flyby)	12.81	485 *(45 day stay)*
Elliptical Mars Orbit (w/ Venus flyby)	8.12	588 *(45 day stay)*
Mars flyby	9.01	501 *(0 day stay)*
Mars flyby (w/ Venus flyby)	6.07	582 *(0 day stay)*
Phobos/Deimos	*Similar requirements to Mars*	

- Many Mars/Phobos/Deimos mission trajectories pass within Venus distance ($\sim$0.7 AU) of the Sun, or closer (thermal/radiation issues)

No round-trip mission to Mars (orbit, surface, or flyby) or Phobos/Deimos is possible with both $\Delta v \leq$12 km/s AND mission duration $\leq$450 days.

Putting Accessibility Into Context

- As of 2015-03-31, **1382** NHATS-compliant NEAs have been discovered
- Of those,
  - **49** can be visited and returned from for less Δv than **low lunar orbit**
  - **580** can be visited and returned from for less Δv than **the lunar surface**
  - All **1382** are more accessible than **Mars, Phobos, or Deimos**
- More and more NHATS-compliant NEAs are being discovered and identified
- The NHATS data processing is automated, observers are automatically notified, web-site is updated daily

(Available Online at: http://www.lpi.usra.edu/sbag/science/)

Accessible Near-Earth Asteroids (NEAs)

Goals of the Near-Earth Object Human Space Flight Accessible Targets Study (**NHATS**):

- Monitor the accessibility of the NEA population for exploration missions.
- Characterize the population of **accessible NEAs**.
- Rapidly notify observers so that crucial follow-up observations can be obtained.

NHATS data shown here current as of: 2015-01-02

NHATS Web-site: http://neo.jpl.nasa.gov/nhats/ **NHATS Daily Updates:** https://lists.nasa.gov/mailman/listinfo/nhats

Chart by: Brent W. Barbee (NASA/GSFC)

Selected NHATS Statistics:

Known NEAs: 11,963

NHATS NEAs: 1,327 (~11.0% of known)

Mean *H* for Known NEAs: 21.919

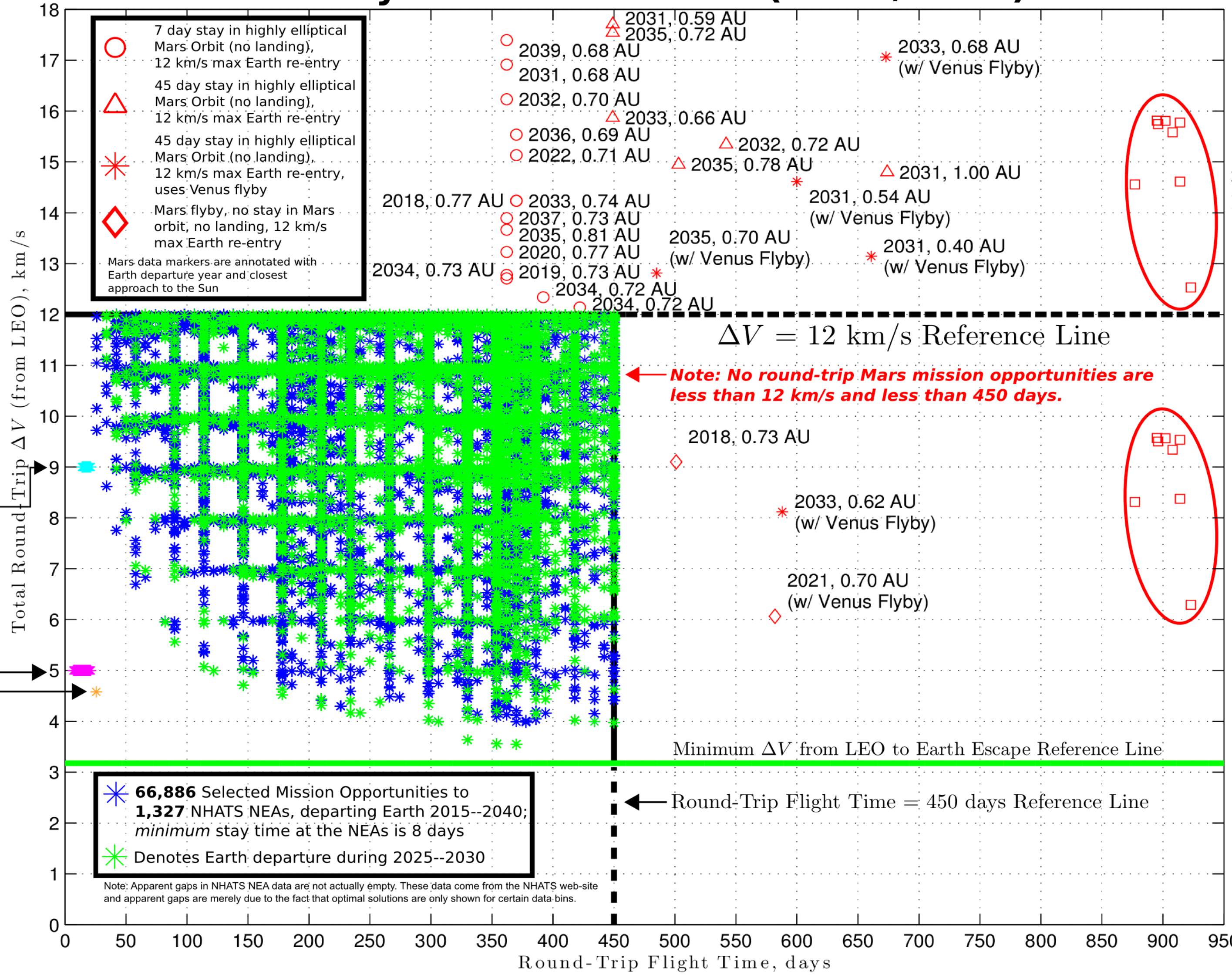
Mean *H* for NHATS NEAs: 24.878

NHATS NEAs by Orbit Type:
Atiras: 0% (0% of Atiras)
Atens: 23% (34% of Atens)
Apollos: 60% (12% of Apollos)
Amors: 17% (5% of Amors)

NHATS NEAs SMA (AU): 0.76, 1.16, 1.82 (Min, Mean, Max)

NHATS NEAs ECC: 0.01, 0.22, 0.45 (Min, Mean, Max)

NHATS NEAs INC (deg): 0.02, 5.19, 16.25 (Min, Mean, Max)



Round-Trip to Lunar Surface

Notes on Earth re-entry speed:
- Earth re-entry speed is approx. 11 km/s for lunar missions / ARRM
- Max Earth re-entry speed for NHATS is 12 km/s; many NHATS mission opportunites have < 12 km/s re-entry

Round-Trip to Low Lunar Orbit (no landing)

ARRM (human visitation of captured NEA in lunar DRO)

Note: Round-trip ΔV and flight time for missions to Phobos or Deimos are similar to Round-trip ΔV and flight time for Mars missions.

2031--2046 Earth Departures, ~500 day stay on Mars surface, 12 km/s max Earth re-entry

2031--2046 Earth Departures, ~500 day stay in highly elliptical Mars Orbit (no landing), 12 km/s max Earth re-entry

Note: Some round-trip trajectories entering Mars orbit will require additional ΔV, up to 1 km/s (or more, in some cases), for incoming/outgoing asymptote alignment. This is not reflected in the data shown here.

Mars Trajectory Data Sources:

7 day stay Mars data: Folta, D., Barbee, B. W., Englander, J., Vaughn, F., Lin, T. Y., "Optimal Round-Trip Trajectories for Short Duration Mars Missions," AAS/AIAA Paper AAS 13-808, August 2013
45 day stay Mars data: Folta, D., Barbee, B. W., Vaughn, F., "Analysis of Short Duration Round-Trip Mars Mission Opportunities During the Mid-2030s," Internal NASA/GSFC presentation, November 2011
500 day stay Mars data*: Drake, B. G., ed. "Human Exploration of Mars Design Reference Architecture 5.0 Addendum," NASA/SP-2009-566-ADD, July 2009, http://www.nasa.gov/pdf/373667main_NASA-SP-2009-566-ADD.pdf *(w/ adjustments by B. W. Barbee for 12 km/s max Earth re-entry)
Mars flyby data: Adamo, D. R. analysis of http://inspirationmars.org/Written_Testimony_DTito_Nov2013.pdf and http://www.youtube.com/watch?v=pdu7Kk5si1k", with input from Loucks, M.

NAC Findings/Recommendations

Excerpt from page 4 of the 4 August 2014 letter to the NASA Administrator from the NASA Advisory Council (NAC);

Major Reasons for Proposing the Recommendation: NASA's current Asteroid Initiative has three elements: (1) the search for and identification of Near Earth Asteroid (NEA) targets; (2) redirection of one NEA target to near-lunar orbit; (3) astronaut crew to cis-lunar space to rendezvous with the target and conduct operations. The cost of the second element (asteroid redirect, e.g., ARM) is poorly defined at present. The other elements of the Asteroid Initiative (target search and flights to cis-lunar space) still have merit even if the redirect mission does not take place. It must also be noted that ARM is not a substitute for a mission to an asteroid in its native orbit, which appears to be possible at a lower launch energy than previously believed based on recent data[2-4]. Such a long duration deep space mission would be a logical step toward the horizon goal of humans to Mars. We have concerns that the ARM mission as currently defined may pose an unacceptable cost and technical risk. A prudent response to such concerns is to conduct and independent cost and technical assessment prior to selection.

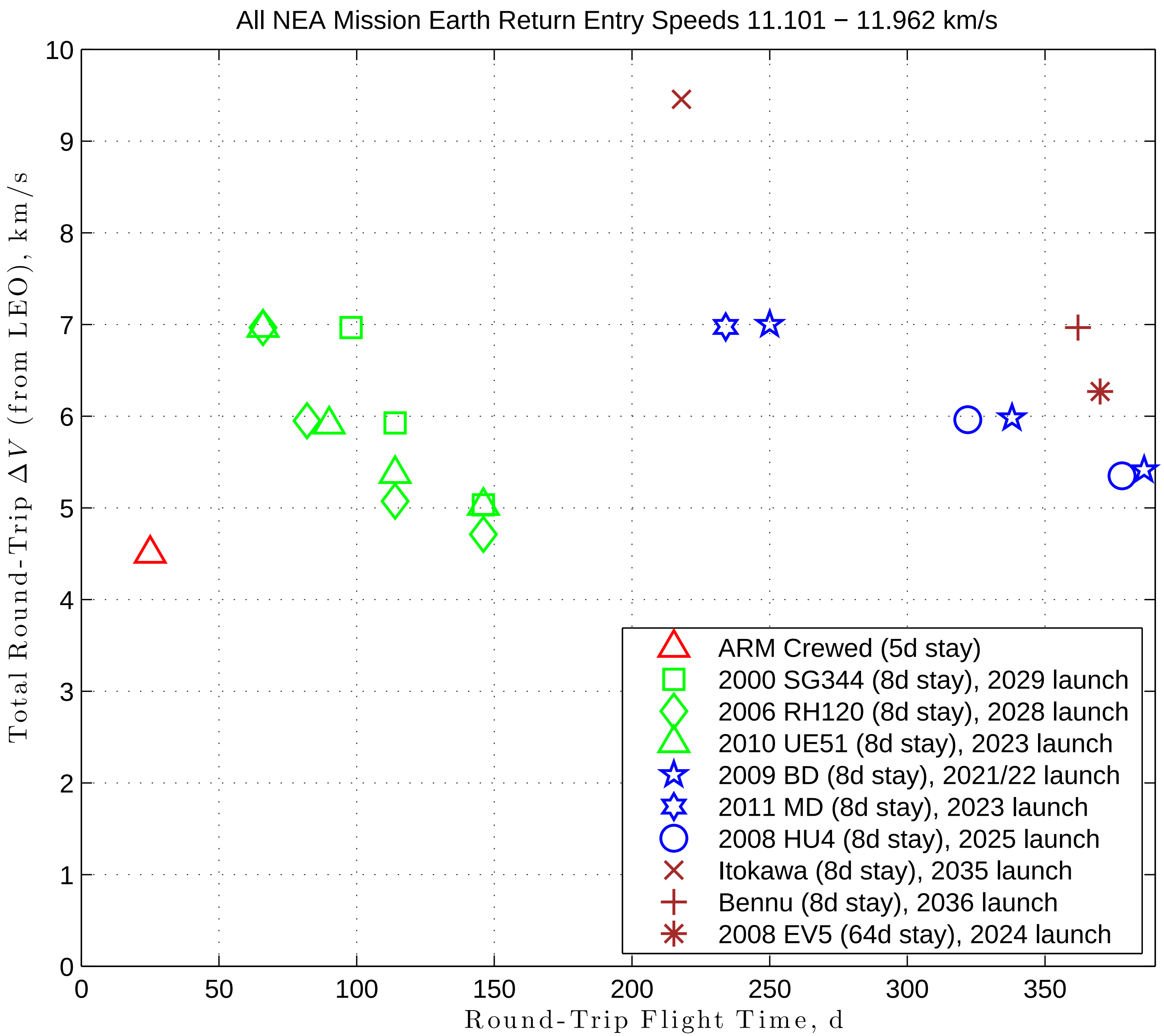
[2]*NHATS: Near-Earth Object Human Space Flight Accessible Targets Study.* *http://neo.jpl.nasa.gov/nhats/*

[3]*Barbee, B. (2014). NASA Small Bodies Assessment Group (SBAG) Science Nuggets.* *http://www.lpi.usra.edu/sbag/science/NHATS_Accessible_NEAs_Summary.png*

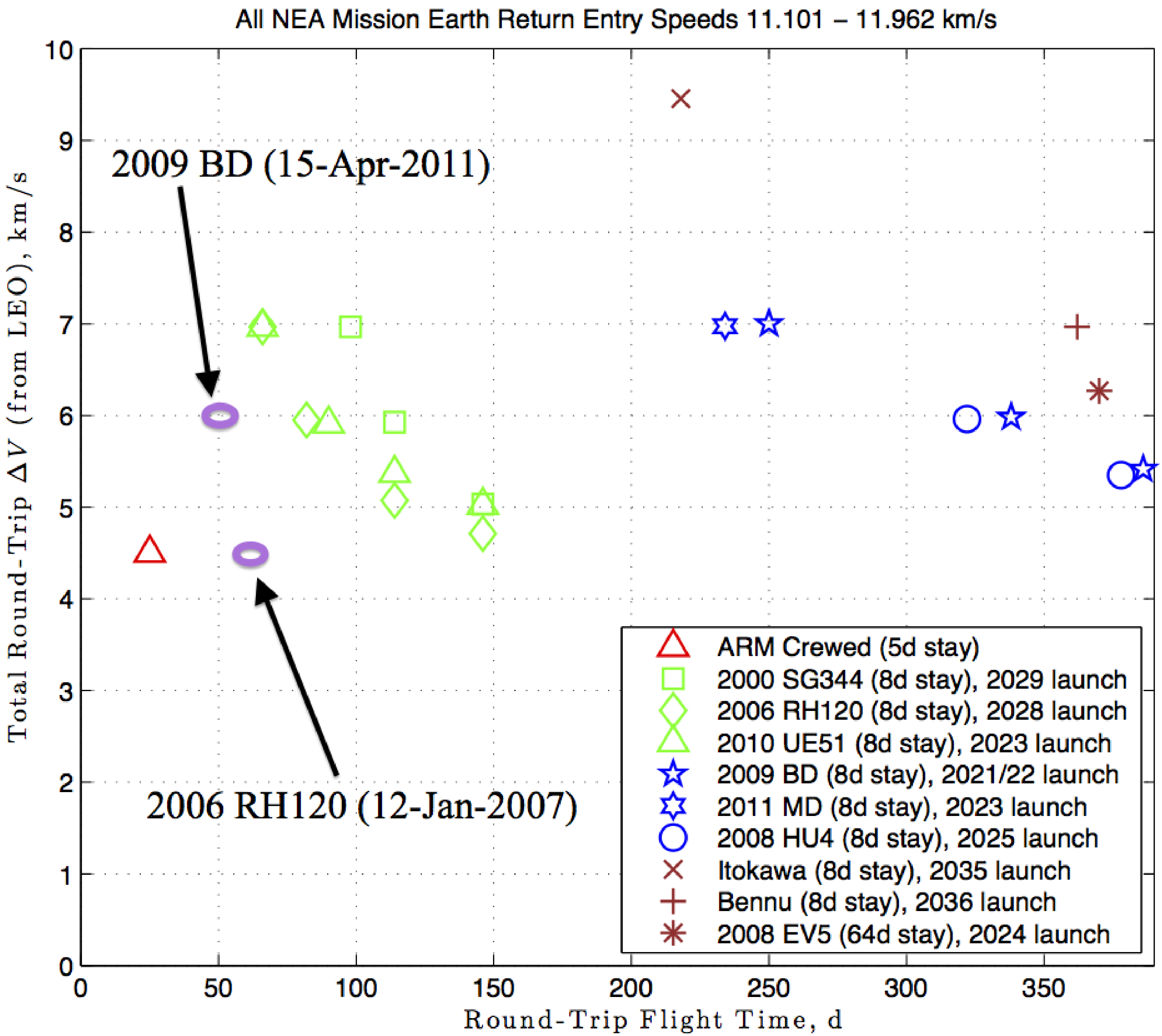
[4]*Barbee, B., Abell, P.A., Adamoc, D.A., Alberdinga, C.M., Mazanek, D.D., Johnson, L.N., Yeomans, D.Y., Chodas, P.W., Chamberlin, A.B., Friedenseng, V.P. (2013). "The Near-Earth Object Human Space Flight Accessible Targets Study: An Ongoing Effort to Identify Near-Earth Asteroid Destinations for Human Explorers." Planetary Defense Conference 2013 IAA-PDC13-04-13.*

(http://www.nasa.gov/offices/nac/meetings/JULY-30-31-2014_presentations.html)
(http://www.nasa.gov/sites/default/files/files/SquyresLetterToBolden_tagged.pdf)
(http://www.nasa.gov/sites/default/files/files/SquyresLetterToBolden.pdf)

Comparisons to ARM

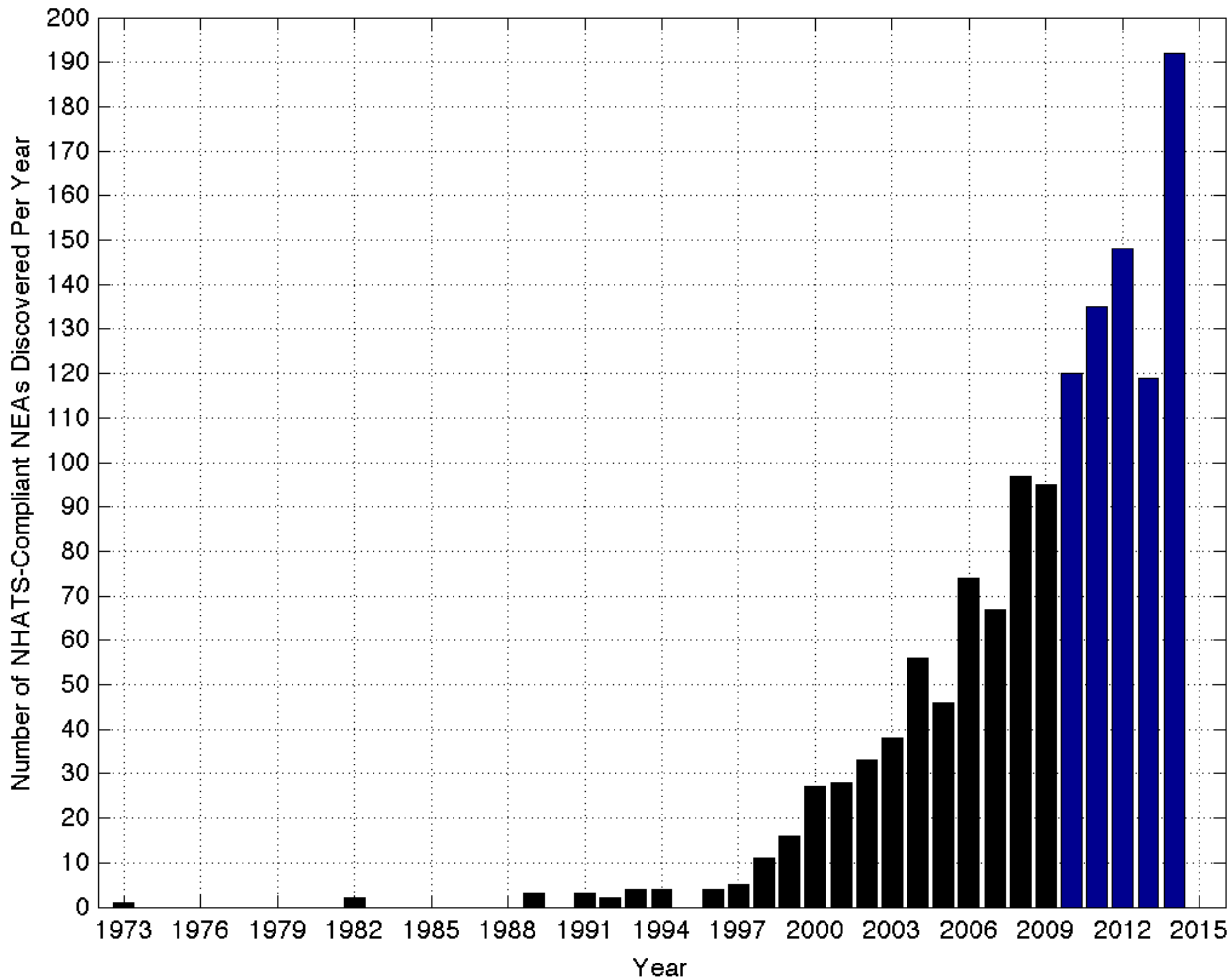


Comparisons to ARM



NHATS-Compliant NEA Discovery Rate

- http://neo.jpl.nasa.gov/news/news189.html
- The number of known NHATS-compliant NEAs has doubled since 2010



Conclusions and Findings

- **Many accessible NEOs have been discovered and identified.**
  - We have an automated system to monitor the accessibility of the NEA population (NHATS).
- **It is likely that many more accessible NEOs are waiting to be found.**
  - Further study is required to learn what modern NEO population models have to say on this point.
- **Current survey capabilities tend to discover NEOs very close to the times of their optimal mission opportunities.**
  - A space-based NEO survey telescope is needed to discover NEOs with implementable mission opportunities (far enough in advance of their mission opportunities).
  - Such an asset would simultaneously benefit human exploration, planetary defense, and science.

NHATS web-site:

http://neo.jpl.nasa.gov/nhats/

NHATS data table:

http://neo.jpl.nasa.gov/cgi-bin/nhats

NHATS mailing list:

https://lists.nasa.gov/mailman/listinfo/nhats